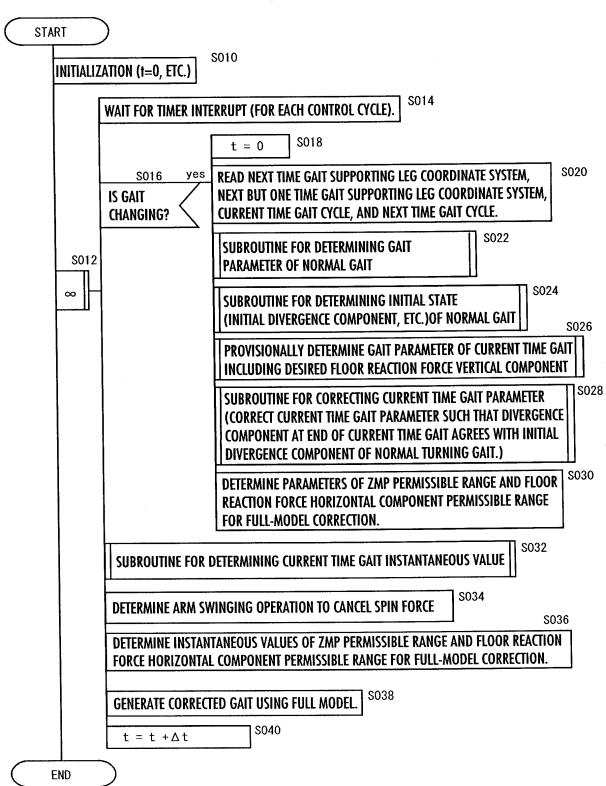
## FIG.9



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#### FIG.11

S024

**ENTRY** 

S2000

SUBSTITUTE VALUES OF 2ND TURNING GAIT PARAMETER INCLUDING (Xs, Vxs,  $\omega$ bs, ZMPrecpeak) DETERMINED ONE STEP BEFORE INTO 1ST TURNING GAIT PARAMETER, AND SUBSTITUTE VALUES OF 1ST TURNING GAIT PARAMETER DETERMINED ONE STEP BEFORE INTO 2ND TURNING GAIT PARAMETER.

S2002-1

BRING VALUES OF PRIORITY PARAMETERS OF NORMAL GAIT PARAMETER EXCLUDING (Xs, Vxs,  $\omega$ bs, ZMPrecpeak) CLOSE TO VALUES DETERMINED BY PROCESSING OF S022.

S2004-1

BASED ON NORMAL GAIT PARAMETER, SEARCH FOR NORMAL GAIT THAT SATISFIES BOUNDARY CONDITION AND DETERMINE (Xs, Vxs,  $\omega$  bs, ZMPrecpeak).

S2002-2

BRING VALUES OF PRIORITY PARAMETERS OF NORMAL GAIT PARAMETER EXCLUDING (Xs, Vxs,  $\omega$ bs, ZMPrecpeak) FURTHER CLOSE TO VALUES DETERMINED BY PROCESSING OF S022.

S2004-2

BASED ON NORMAL GAIT PARAMETER, SEARCH FOR NORMAL GAIT THAT SATISFIES BOUNDARY CONDITION AND DETERMINE (Xs, Vxs,  $\omega$ bs, ZMPrecpeak).

S2002-n

MATCH VALUES OF PRIORITY PARAMETERS OF NORMAL GAIT PARAMETER EXCLUDING (Xs, Vxs,  $\omega$ bs, ZMPrecpeak) WITH VALUES DETERMINED BY PROCESSING OF SO22.

S2004-n

BASED ON NORMAL GAIT PARAMETER, SEARCH FOR NORMAL GAIT THAT SATISFIES BOUNDARY CONDITION AND DETERMINE (Xs, Vxs,  $\omega$ bs, ZMPrecpeak).

S2006

BASED ON NORMAL TURNING GAIT, DETERMINE INITIAL BODY HORIZONTAL POSITION, VELOCITY, POSTURE ANGLE, ANGULAR VELOCITY (X0, Vx0,  $\theta$  b0,  $\omega$ b0) and initial body vertical position and velocity (Z0, Vz0) at original initial time 0.

DETERMINE NORMAL TURNING INITIAL DIVERGENCE COMPONENT q[0] ACCORDING TO THE FOLLOWING EXPRESSION:

S2008

 $q[0] = X0 + Vx0 / \omega 0$ 

S2010

DETERMINE q", WHICH IS THE VALUE OF NORMAL TURNING INITIAL DIVERGENCE COMPONENT q[0] OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF CURRENT TIME'S GAIT, AND (Z0",Vz0"), WHICH ARE VALUES OF INITIAL BODY VERTICAL POSITION/VELOCITY OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF CURRENT TIME'S GAIT.

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## **FIG.12**

 $S2004-m (m=1, 2, \cdots, n)$ **ENTRY** S1200 BASED ON NORMAL TURNING GAIT PARAMETER, DETERMINE INITIAL STATES (STATES AT INITIAL TIME Ts) OF FOOT POSITION/POSTURE, BODY POSTURE ANGLE  $\, heta$  bs and ARM Postures. S1202 TAKE CURRENT VALUES OF (Xs, Vxs,  $\omega$  bs, ZMPrecpeak) AS INITIAL VALUE CANDIDATES OF INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE. S1206 DETERMINE INITIAL BODY VERTICAL POSITION/VELOCITY (Zs, Vzs). S1208 USING DYNAMIC MODEL, GENERATE NORMAL GAIT ON THE BASIS OF NORMAL TURNING GAIT PARAMETER INCLUDING ZMPrecpeak, TAKING  $\theta$  bs,(Xs, Vxs,  $\omega$ bs), (Zs,Vzs) AS INITIAL STATES OF BODY. S1210 CONVERT TERMINAL BODY HORIZONTAL POSITION, VELOCITY, POSTURE ANGLE, AND ANGULAR VELOCITY OF GENERATED GAIT INTO VALUES OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF NEXT STEP, AND DENOTE THE VALUES BY (Xe, Vxe,  $\theta$  be,  $\omega$  be). S1212 **BOUNDARY CONDITION ERRORS (errx, errv, err**  $\theta$  , err  $\omega$ ) S1204 = (Xs, Vxs,  $\theta$  bs,  $\omega$  bs)-(Xe, Vxe,  $\theta$  be,  $\omega$  be) LEAVE REPETITION LOOP. ARE ALL errx, errv, err  $\theta$  b, AND err  $\omega$  b WITHIN PERMISSIBLE RANGES? S1216 DETERMINE A PLURALITY OF INITIAL VALUE CANDIDATES (Xs+ $\triangle$ Xs, Vxs,  $\omega$ bs, ZMPrecpeak), (Xs,  $Vxs+\triangle Vxs$ ,  $\omega$  bs, ZMPrecpeak), (Xs, Vxs,  $\omega$  bs+ $\Delta \omega$  bs, ZMPrecpeak), (Xs, Vxs,  $\omega$  bs, ZMPrecpeak+ $\triangle$  ZMPrecpeak) IN THE VICINITY OF (Xs, Vxs,  $\omega$  bs, ZMPrecpeak), AND BASED ON THEM, DETERMINE BOUNDARY CONDITION ERROR CORRESPONDING TO EACH OF THEM AS DESCRIBED ABOVE. **S1218** DETERMINE NEW CANDIDATES (Xs, Vxs,  $\omega$ bs, ZMPrecpeak) ON THE BASIS OF BOUNDARY CONDITION ERRORS CORRESPONDING TO (Xs, Vxs,  $\omega$  bs, ZMPrecpeak) AND EACH OF CANDIDATES IN THE VICINITY THEREOF.

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## **FIG.16**

S026  ENTRY  DETERMINE FOOT TRAJECTORY PARAMETER  S600	0
DETERMINE FOOT TRAJECTORY PARAMETER S600	D
DETERMINE FOOT TRAJECTORY PARAMETER	0
DETERMINE FOOT TRAJECTORY PARAMETER	0
OF CURRENT TIME GAIT.	
DETERMINE REFERENCE BODY POSTURE TRAJECTORY	S602
PARAMETER OF CURRENT TIME GAIT.	
DETERMINE ARM LOSIONE INVICTION LANAMITIEN	S604
OF CURRENT TIME GAIT.	
DETERMINE FLOOR REACTION FORCE VERTICAL COMPONENT	S606
TRAJECTORY PARAMETER OF CURRENT TIME GAIT.	
DETERMINE FLOOR REACTION FORCE HORIZONTAL	S60
COMPONENT PERMISSIBLE RANGE [Fxmin, Fxmax] OF CURRENT TIME GAIT.	
OF CORRENT TIME GAIT.	
PROVISIONALLY DETERMINE ZMP TRAJECTORY PARAMETER	S61
OF CURRENT TIME GAIT.	
SET BODY INCLINATION ANGLE RESTORING PERIOD [Ta, Tb]	S612
RETURN	

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**FIG.18** 

 $S2104-m (m=1, 2, \cdots, n)$ 

**ENTRY** 

\$1700

TAKE CURRENT VALUES OF (a, ZMPrecpeaka, ZMPrecpeakb) AS INITIAL VALUE CANDIDATES OF ZMP CORRECTED PARAMETER CANDIDATE a AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATES (ZMPrecpeaka, ZMPrecpeakb), RESPECTIVELY.

S1704

S1706

CALCULATE CURRENT TIME GAIT USING DYNAMIC MODEL UNTIL TERMINATING TIME ON THE BASIS OF PARAMETER OBTAINED BY CORRECTING CURRENT ZMP TRAJECTORY PARAMETER BY ZMP CORRECTED PARAMETER CANDIDATE a, BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATES (ZMPrecpeaka, ZMPrecpeakb), AND OTHER CURRENT TIME GAIT PARAMETERS.

DETERMINE TERMINAL DIVERGENCE COMPONENT q0[k] according to the following expression from Body Position/Velocity (Xe, Ve)

AT TERMINATING END OF CURRENT TIME GAIT:

 $q0[k] = Xe + Vxe / \omega 0$ 

DETERMINE TERMINAL DIVERGENCE COMPONENT ERROR error ACCORDING TO THE FOLLOWING EXPRESSION:

errq = q0[k] - q''

\$1708

TERMINAL BODY INCLINATION ANGLE ERROR  $\theta$  berr

= NORMAL GAIT INITIAL BODY INCLINATION ANGLE

- CURRENT TIME GAIT INITIAL BODY INCLINATION ANGLE

TERMINAL BODY INCLINATION ANGULAR VELOCITY ERROR  $\omega$  berr

- = NORMAL GAIT INITIAL BODY INCLINATION ANGLE VELOCITY
  - CURRENT TIME GAIT INITIAL BODY INCLINATION ANGULAR VELOCITY

LEAVE REPETITION LOOP.

~~

S1702

ARE ALL errq,  $\theta$  berr, AND  $\omega$  berr WITHIN PERMISSIBLE RANGES?

S1714

S1710

DETERMINE A PLURALITY OF INITIAL VALUE CANDIDATES ( $a + \triangle a$ , ZMPrecpeaka, ZMPrecpeakb),

- (a, ZMPrecpeaka+ △ ZMPrecpeaka, ZMPrecpeakb), AND
- (a, ZMPrecpeaka, ZMPrecpeakb+ △ ZMPrecpeakb) IN THE VICINITY OF
- (a, ZMPrecpeaka, ZMPrecpeakb), AND BASED ON THEM, DETERMINE ERRORS ASSOCIATED WITH EACH OF THEM AS DESCRIBED ABOVE.

DETERMINE NEW PARAMETER CANDIDATES (a, ZMPrecpeaka, ZMPrecpeakb) ON THE BASIS OF (a, ZMPrecpeaka, ZMPrecpeakb) AND ERRORS ASSOCIATED WITH EACH OF INITIAL VALUE CANDIDATES IN THE VICINITY THEREOF.

\$1716

## **FIG.19**

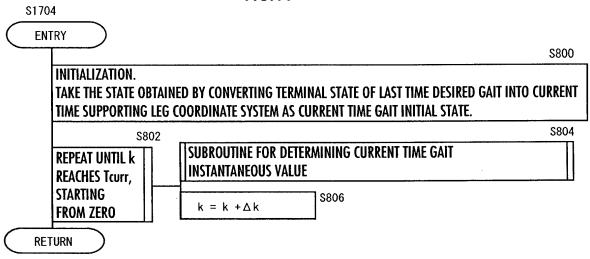
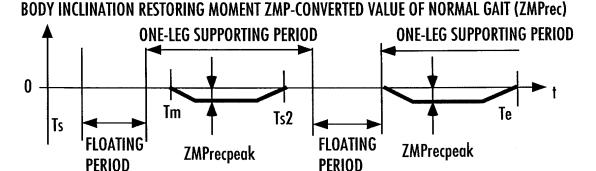


FIG.20



**FIG.21** 

BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE OF CURRENT TIME GAIT (ZMPrec)

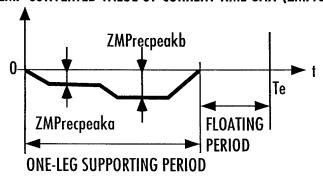
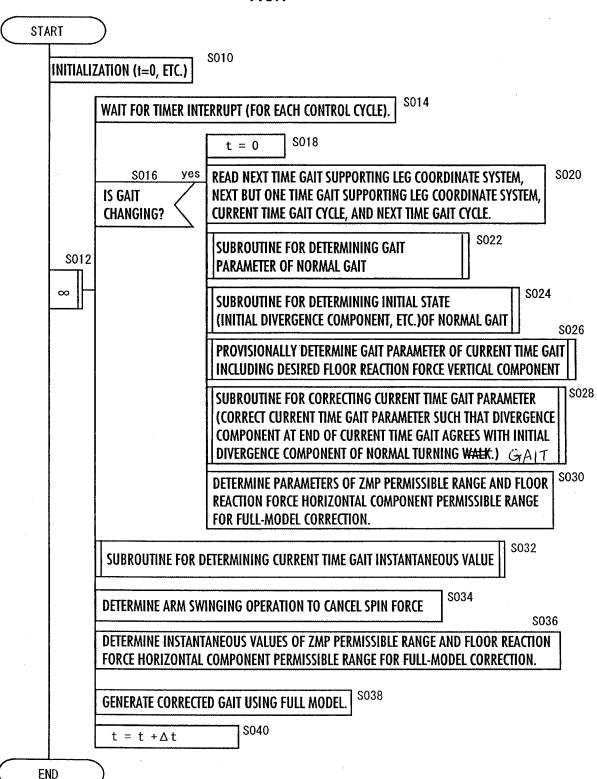


FIG.9



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FIG.11

S024

**ENTRY** 

S2000

SUBSTITUTE VALUES OF 2ND TURNING GAIT PARAMETER INCLUDING (Xs, Vxs,  $\omega$ bs, ZMPrecpe&k) DETERMINED ONE STEP BEFORE INTO 1ST TURNING GAIT PARAMETER, AND SUBSTITUTE VALUES OF 1ST TURNING GAIT PARAMETER DETERMINED ONE STEP BEFORE INTO 2ND TURNING GAIT PARAMETER.

\$2002-1

BRING VALUES OF PRIORITY PARAMETERS OF NORMAL GAIT PARAMETER EXCLUDING (Xs, Vxs,  $\omega$ bs, ZMPrecpeek) CLOSE TO VALUES DETERMINED BY PROCESSING OF SO22.

S2004-1

BASED ON NORMAL GAIT PARAMETER, SEARCH FOR NORMAL GAIT THAT SATISFIES BOUNDARY CONDITION AND DETERMINE (Xs, Vxs, ωbs, ZMPrecpeèk).

S2002-2

BRING VALUES OF PRIORITY PARAMETERS OF NORMAL GAIT PARAMETER EXCLUDING (Xs, Vxs,  $\omega$ bs, ZMPrecpe $^{i}$ k) Further close to values determined by Processing of S022.

S2004-2

BASED ON NORMAL GAIT PARAMETER, SEARCH FOR NORMAL GAIT THAT SATISFIES BOUNDARY CONDITION AND DETERMINE (Xs, Vxs, ωbs, ZMPrecpeak).

λ

S2002-n

MATCH VALUES OF PRIORITY PARAMETERS OF NORMAL GAIT PARAMETER EXCLUDING (Xs, Vxs,  $\omega$ bs, ZMPrecpeak) WITH VALUES DETERMINED BY PROCESSING OF SO22.

S2004-n

BASED ON NORMAL GAIT PARAMETER, SEARCH FOR NORMAL GAIT THAT SATISFIES BOUNDARY CONDITION AND DETERMINE (Xs, Vxs,  $\omega$ bs, ZMPrecpeak).

a

\$2006

BASED ON NORMAL TURNING GAIT, DETERMINE INITIAL BODY HORIZONTAL POSITION, VELOCITY, POSTURE ANGLE, ANGULAR VELOCITY (X0, Vx0,  $\theta$  b0,  $\omega$  b0) and initial body vertical position and velocity (Z0, Vz0) at original initial time 0.

DETERMINE NORMAL TURNING INITIAL DIVERGENCE COMPONENT q[0] ACCORDING TO THE FOLLOWING EXPRESSION:

S2008

 $q[0] = X0 + Vx0 / \omega 0$ 

S2010

DETERMINE q", WHICH IS THE VALUE OF NORMAL TURNING INITIAL DIVERGENCE COMPONENT q[0]
OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF CURRENT TIME'S GAIT, AND (ZO",VzO"),
WHICH ARE VALUES OF INITIAL BODY VERTICAL POSITION/VELOCITY OBSERVED FROM SUPPORTING LEG
COORDINATE SYSTEM OF CURRENT TIME'S GAIT.

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### **FIG.12**

 $S2004-m (m=1, 2, \cdots, n)$ **ENTRY** \$1200 BASED ON NORMAL TURNING GAIT PARAMETER, DETERMINE INITIAL STATES (STATES AT INITIAL TIME Ts) OF FOOT POSITION/POSTURE, BODY POSTURE ANGLE  $\theta$  bs and ARM Postures. \$1202 TAKE CURRENT VALUES OF (Xs, Vxs,  $\omega$ bs, ZMPrecpeek) AS INITIAL VALUE CANDIDATES OF INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE. S1206 DETERMINE INITIAL BODY VERTICAL POSITION/VELOCITY (Zs, Vzs). \$1208 USING DYNAMIC MODEL, GENERATE NORMAL GAIT ON THE BASIS OF NORMAL TURNING GAIT PARAMETER INCLUDING ZMPrecpeek, TAKING  $\theta$  bs,(Xs, Vxs,  $\omega$ bs), (Zs,Vzs) AS INITIAL STATES OF BODY. S1210 CONVERT TERMINAL BODY HORIZONTAL POSITION, VELOCITY, POSTURE ANGLE, AND ANGULAR VELOCITY OF GENERATED GAIT INTO VALUES OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF NEXT STEP, AND DENOTE THE VALUES BY (Xe, Vxe,  $\theta$  be,  $\omega$ be). S1212 BOUNDARY CONDITION ERRORS (errx, errv, err  $\theta$ , err  $\omega$ ) S1204 = (Xs, Vxs,  $\theta$  bs,  $\omega$  bs)-(Xe, Vxe,  $\theta$  be,  $\omega$  be) \$1214 yes  $\infty$ LEAVE REPETITION LOOP. ARE ALL errx, erry, err  $\theta$  b, AND err  $\omega$  b WITHIN PERMISSIBLE RANGES? \$1216 DETERMINE A PLURALITY OF INITIAL VALUE CANDIDATES ( $Xs + \triangle Xs$ ,  $Vxs = \omega bs$ , ZMPrecpeak), (Xs,  $Vxs + \triangle Vxs$ ,  $\omega bs$ , ZMPrecpeck), (Xs, Vxs,  $\omega bs + \triangle \omega bs$ , ZMPrecpeck), (Xs, Vxs,  $\omega$  bs, ZMPrecpeek+  $\triangle$  ZMPrecpeek) IN THE VICINITY OF (Xs, Vxs,  $\omega$  bs, ZMPrecpeek), AND BASED ON THEM, DETERMINE BOUNDARY CONDITION ERROR CORRESPONDING TO EACH OF THEM AS DESCRIBED ABOVE. S1218 DETERMINE NEW CANDIDATES (Xs, Vxs, ωbs, ZMPrecpetk) ON THE BASIS OF BOUNDARY CONDITION ERRORS CORRESPONDING TO (Xs, Vxs,  $\omega$  bs, ZMPrecpe&k) AND EACH OF CANDIDATES IN THE VICINITY THEREOF.

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## **FIG.16**

S026		
ENTRY		
DE	TERMINE FOOT TRAJECTORY PARAMETER	600
OF	CURRENT TIME GAIT.	
ļ		1 S602
	TERMINE REFERENCE BODY POSTURE TRAJECTORY RAMETER OF CURRENT TIME GAIT.	3002
		1
	TERMINE ARM POSTURE TRAJECTORY PARAMETER CURRENT TIME GAIT.	S604
		_
1	TERMINE FLOOR REACTION FORCE VERTICAL COMPONENT AJECTORY PARAMETER OF CURRENT TIME GAIT.	\$606
		_
	TERMINE FLOOR REACTION FORCE HORIZONTAL	S608
	MPONENT <del> LIMIT</del> RANGE [Fxmin, Fxmax] CURRENT TIME GAIT.	
	PERMISSIBLE	J
4	OVISIONALLY DETERMINE ZMP TRAJECTORY PARAMETER CURRENT TIME GAIT.	S610
SE	F BODY INCLINATION ANGLE RESTORING PERIOD [Ta, Tb]	S612
		1
RETUR	N )	

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**FIG.18**  $S2104-m (m=1, 2, \dots, n)$ **ENTRY** TAKE CURRENT VALUES OF (a, ZMPrecpeaka, ZMPrecpeakb) AS INITIAL VALUE CANDIDATES OF ZMP CORRECTED PARAMETER CANDIDATE a AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATES (ZMPrecperka, ZMPrecperkb), RESPECTIVELY. S1704 CALCULATE CURRENT TIME GAIT USING DYNAMIC MODEL UNTIL TERMINATING TIME ON THE BASIS OF PARAMETER OBTAINED BY CORRECTING CURRENT ZMP TRAJECTORY PARAMETER BY ZMP CORRECTED PARAMETER CANDIDATE a, BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATES (ZMPrecpeèka, ZMPrecpeekb), AND OTHER CURRENT TIME GAIT PARAMETERS. S1706 DETERMINE TERMINAL DIVERGENCE COMPONENT qO[k] ACCORDING TO THE FOLLOWING EXPRESSION FROM BODY POSITION/VELOCITY (Xe, Ve) AT TERMINATING END OF CURRENT TIME GAIT:  $q0[k] = Xe + Vxe / \omega 0$ \$1708 DETERMINE TERMINAL DIVERGENCE COMPONENT ERROR errq **ACCORDING TO THE FOLLOWING EXPRESSION:** errq = q0[k] - q''S1710 TERMINAL BODY INCLINATION ANGLE ERROR  $\theta$  berr = NORMAL GAIT INITIAL BODY INCLINATION ANGLE - CURRENT TIME GAIT INITIAL BODY INCLINATION ANGLE TERMINAL BODY INCLINATION ANGULAR VELOCITY ERROR  $\omega$  berr = NORMAL GAIT INITIAL BODY INCLINATION ANGLE VELOCITY - CURRENT TIME GAIT INITIAL BODY INCLINATION ANGULAR VELOCITY S1712 yes S1702 LEAVE REPETITION LOOP. ARE ALL errq,  $\theta$  berr, AND  $\omega$  berr WITHIN PERMISSIBLE RANGES?  $\infty$ DETERMINE A PLURALITY OF INITIAL VALUE CANDIDATES ( $a + \triangle a$ , ZMPrecpeaka, ZMPrecpeakb), (a, ZMPrecpeeka+ △ ZMPrecpeeka, ZMPrecpeekb), AND (a, ZMPrecpeaka, ZMPrecpeakb+ △ ZMPrecpeakb) IN THE VICINITY OF (a, ZMPrecpeeka, ZMPrecpeekb), AND BASED ON THEM, DETERMINE ERRORS ASSOCIATED WITH EACH OF THEM AS DESCRIBED ABOVE. S1716 DETERMINE NEW PARAMETER CANDIDATES (a, ZMPrecpeaka, ZMPrecpeakb) ON THE BASIS OF (a, ZMPrecpeaka, ZMPrecpeakb) AND ERRORS ASSOCIATED WITH EACH OF INITIAL VALUE

RETURN

CANDIDATES IN THE VICINITY THEREOF.

**FIG.19** 

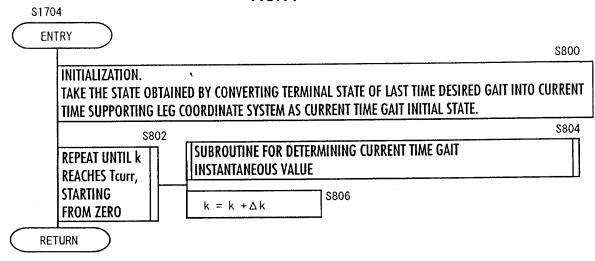
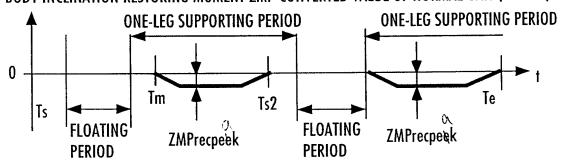


FIG.20
BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE OF NORMAL GAIT (ZMPrec)



**FIG.21** 

BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE OF CURRENT TIME GAIT (ZMPrec)

